CHAPTER 3.
EXPERIMENTAL APPARATUS AND APPROACH

3.1. Data-Collection Procedure

Considering the major objectives of this research, the following types of data were collected:

1. Detailed bathymetry data (x,y,z of the bed) to enable determination of bedform geometry
2. Velocity data at sufficient time scales to determine both mean and fluctuating components at locations throughout the vertical (especially in the near-bed environment), and along the bedform profile
3. Suspended-sediment concentration data to allow estimation of the concentration profile
4. Bed-material samples to enable determination of the bed-sediment size distribution
5. River stage at various locations along the river to enable computation of the water surface slope

For each data set, the bathymetry data were collected using a boat-mounted 200 kHz Odum Hydrographic Systems Hydrotrac digital Fathometer, with centimeter accuracy, in concert with a Trimble AgGPS™ 124/132 differentially corrected global positioning system (DGPS), with sub-meter horizontal accuracy. The data from these instruments were synchronized and logged using Oceangraphic Systems, Inc. HYPACK™ software. Multiple transects were collected running parallel with the river, on approximately 20-m spacing on the Missouri River and 5- m spacing on the Kankakee River.

Detailed velocity data were collected from a stationary boat using both a downlooking 600-kHz acoustic Doppler current profiler (ADCP) and a 10-MHz acoustic Doppler velocimeter (ADV) (for the KANK-1 data, a 1200-kHz ADCP was used). The exact position of each vertical was determined by DGPS. The ADCP was mounted to the side of the boat, whereas the ADV was mounted on a modified P-61 sediment sampler suspended from the boat by a cable. Suspended-sediment data were collected via a pump sampler connected to intakes on the modified P-61 sediment sampler. Bed-material samples were collected using a US BM-54 bed-material sampler. River stages were collected by a combination of automated stage sensors, tape downs from known reference marks, and observer readings from wire-weight gages.

To begin the collection of the detailed velocity data, two anchors were deployed from the boat upstream on both sides of the dune field where the measurements were taken. This deployment allowed the boat position to be maintained with a minimum of lateral movement. A sea anchor (a large bucket(s) with holes drilled to allow water to pass through) was deployed from the stern of the boat to add further stability to the anchored position. The sea anchor was required particularly when any cross winds were present.

The verticals were located, such that spacing was a minimum at the crest and lee of a bedform, with maximum spacing along the stoss side of the dune (where changes are more gradual). Ideally, around 15 to 20 verticals were intended to provide a balance between the spatial detail needed and time constraints for collection of all necessary measurements (data collection began at dawn and terminated at dark). The procedures for data collection at KANK-1 and MO-1 essentially were the same. At each vertical, one ADV, mounted on the bow of the boat, measured the velocity near the water surface . A downlooking ADCP, mounted on the bow (but aft of the ADV), measured point velocities at numerous 25 cm bins from near the water surface to near the channel bed. The boat and equipment used for measurements at MO-1 (and MO-2) are illustrated in figure 3.1. As approximately 6% of the flow depth near the bed is not measurable by the ADCP (Kevin Oberg, U.S. Geological Survey, Office of Surface Water Acoustics Specialist, oral communication, 2002), the modified P-61 was lowered to the bed and the two ADVs mounted on the modified P-61 measured the velocity at locations ranging from 3 to 12 cm from the bed for the bottommost ADV and from 40 to 48 cm above the bed for the uppermost ADV. The ADV has the capacity to measure the distance from the probe to the boundary at the start of the measurement. This measuring capacity was used as the determinant for the elevation where the bottommost ADV collected data. As the two ADVs were a fixed distance apart on the mount, the elevation of the uppermost (upward-looking) ADV was dependent on the elevation of the bottommost ADV. The capacity of the ADV to measure the distance to the boundary greatly decreased in highly sand-laden water, as was the case with the MO-1 data. In this instance, an elevation of 5.7 cm above the bed was assumed for all data collected with the bottommost ADV. For each vertical of the KANK-1 and MO-1 tests, velocity data were collected for a total of 10 minutes.

After analysis of the MO-1 data, it was realized that more ADV data would be needed throughout the vertical (and not only at two points near the bed and one point near the surface) to enable analysis of Reynolds stresses. This new data collection scheme would require positioning the modified P-61, with ADV's mounted, at various locations in the vertical; the location dependent on measuring the distance from the water surface. In the MO-1 data, the two hoses for the pump-sampler intakes, the two cables for the ADV's, and the cable for the compass/tilt/roll sensor created drag and, thus, would result in the sampler descending through the water column in an ever-increasing angle from the vertical, and sampler instability while in the water column. This sampler instability was not a problem for the MO-1 data as the sampler was placed on the bed, which steadied the sampler, with its lateral location easily computed from the cable angle. However, with the need for making ADV measurements throughout the water column for the MO-2 test, the sampler had to be streamlined. The uppermost upward-looking ADV was removed, along with both pump-sampler intakes. The original P-61 sampling capacity was to be utilized to collect the needed sediment samples. For the MO-2 test, the ADCP still was utilized to collect velocity data from just below the water surface to near the bed, whereas the ADV (mounted on the P-61) was lowered throughout the water column to collect detailed velocity data. The ADV was positioned at increments of 0.1 m for the first meter of elevation above the bed, then positioned every 1 m from there until the water surface, with the uppermost data point being just below the water surface. For each point location of the ADV, velocity data were collected for approximately 2 minutes. The ADCP data were collected the entire time the boat was positioned at each vertical (approximately 30 minutes).

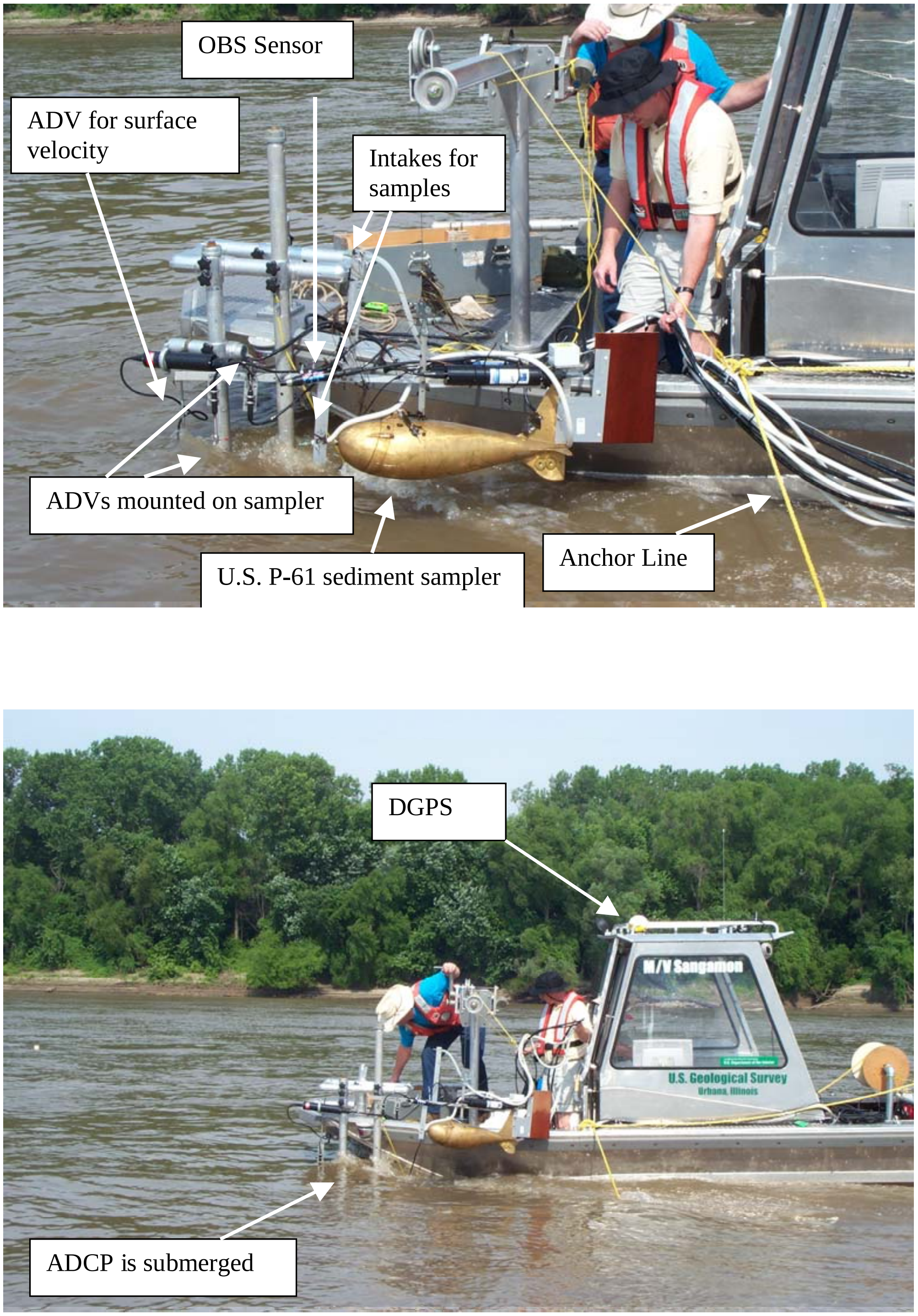


Figure 3.1-- Boat anchored preparing to collect data on the Missouri River at St Charles, Missouri

For the KANK-1 and MO-1 tests, suspended-sediment data were intended to be collected at two points in each vertical using the pump sampler. For the KANK-1 data, two samples were collected (at 10.9 and 68.9 cm above the bed) for each vertical. For the MO-1 data, the lower sampling intake became jammed with sand after the first vertical and suspended-sediment samples only were collected at 68.9 cm above the bed for each vertical. As described earlier, the pump-sampler intakes were eliminated for the MO-2 test, with the intention that the sediment samples would be collected by using the built-in sampling capabilities of the P-61. Unfortunately, no sediment concentration data were collected for MO-2 as the P-61 solenoid mechanism, which opens the sampler nozzle at depth, malfunctioned, preventing sample collection.

3.2. Instrumentation

3.2.1. Acoustic Doppler Velocimeter

The type of ADV used in this research was a 10-MHz unit manufactured by NORTEK, with the capability of collecting three-dimensional velocity data at 25 Hz. The ADV has a bi-static (focal point) acoustic Doppler system, and consists of a transmitter and three receivers. A sampling volume of 9 mm is approximately 5 cm from the probe. This distance eliminates intrusion of the sensor into the flow. ADVs have been used to make velocity and turbulence measurements in many studies. ADV's have been shown to accurately measure Reynolds stresses and mean velocity, even up to 1 cm from the bed for mean velocity and 3 cm for Reynolds stresses (Voulgaris and Trowbridge, 1998).

The NORTEK ADV used in this research (figure 3.2) consists of a probe connected by flexible cable to a signal-conditioning module (both submersible components). The signal-conditioning module, in turn, is connected (using watertight connectors) by high-frequency cable to a processor unit on the boat. The processor unit, in turn, is connected by serial cable to an on-board computer.

As the flexible-cable probe has no capacity for automatic orientation (by use of a built-in compass that is available for fixed-stem probes), a separate compass/tilt/roll sensor (figure 3.2) was attached to the modified P-61 platform to enable determination of probe orientation. Any misalignment of the ADV from the streamwise direction then could be corrected in post-processing of the data.

The sampling time at a point for the ADV was 10 minutes for the KANK-1 and MO-1 data, while it was 2 minutes for most of the MO-2 data (because of time constraints, some points only were sampled for 60 seconds). The required sampling time is dependent on the amount of time needed to determine a stable average of the parameter of interest (e.g. mean velocity or turbulence statistics such as turbulence intensity or Reynolds stress). In general, mean velocity determinations require smaller sample times than for turbulence statistics. Based on laboratory and river data collected early in the research, 1 minute was found to be more than adequate sample time to determine accurate mean velocities. Although mean velocities were a very important data set for this research, it also was desirable to collect velocity data that adequately would describe certain turbulence parameters. One minute sometimes was inadequate for the calculation of Reynolds stresses and turbulence intensity. The sample times used in this research are a balance between trying to collect data long enough to extract turbulence information and adhering to the constraints of time available for daylight sampling. Examples of stationarity analyses conducted on the cumulative averages of the parameters of: streamwise mean velocity, covariance of the streamwise and vertical velocity fluctuations (Reynolds stress), and streamwise turbulence intensity are given in figure 3.3-3.9.   As can be seen, the average mean velocity is described adequately within the first minute of sampling; however, to arrive at a good estimate of the Reynolds stress and turbulence intensity, sampling typically takes longer than 1 minute.

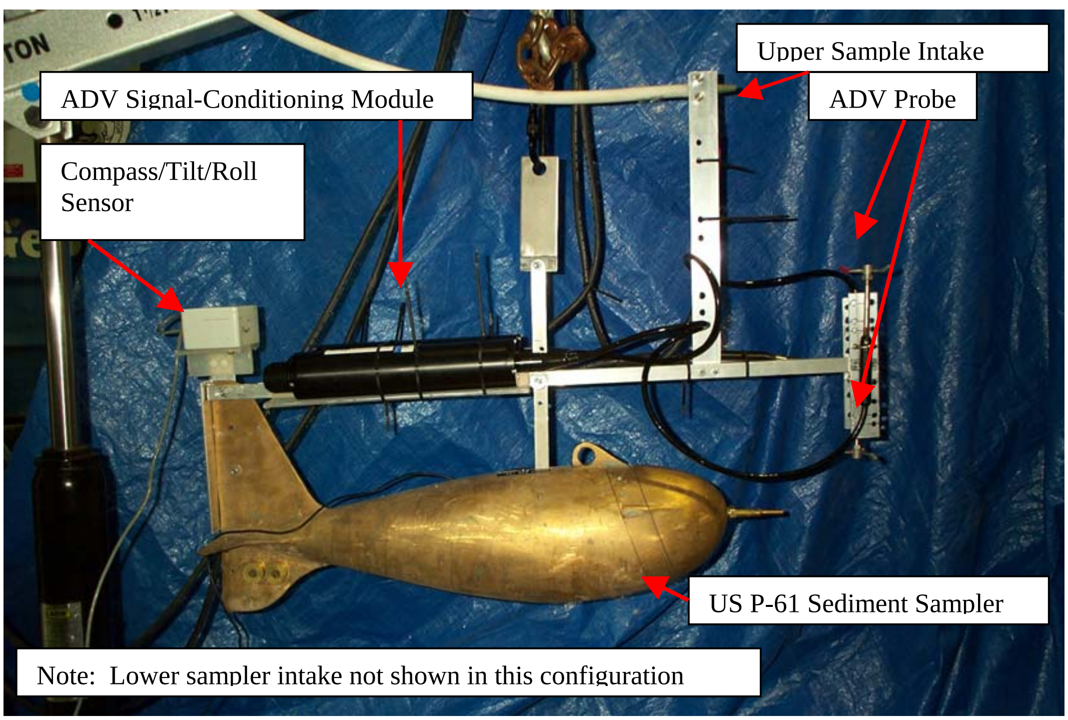


Figure 3.2—Modified P-61 platform with ADVs, compass/tilt/roll sensor, and sampler intake shown

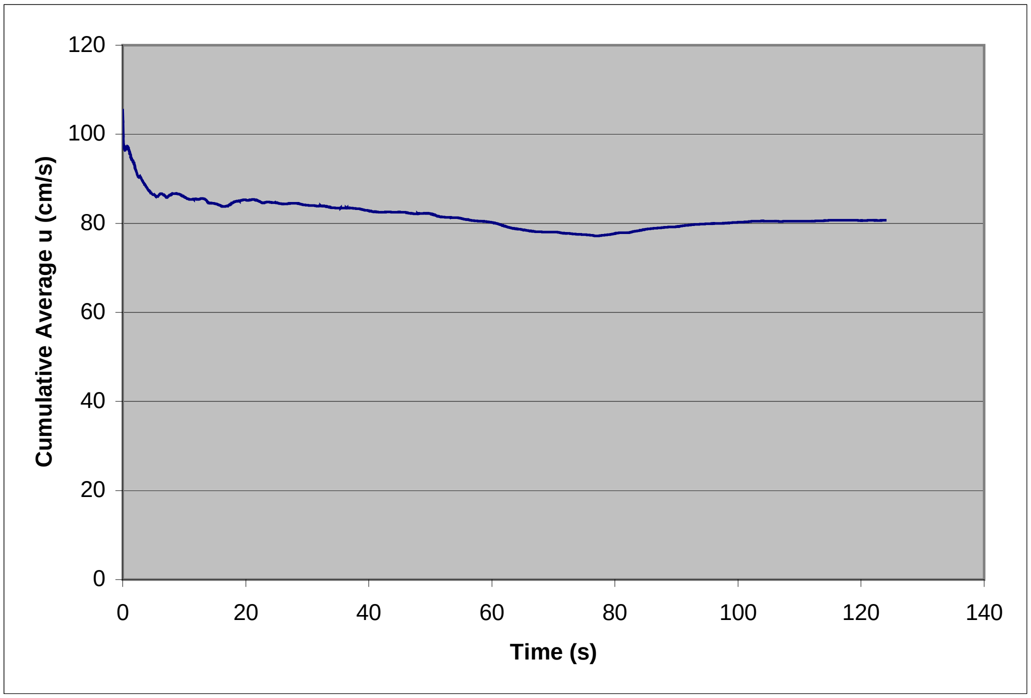


Figure 3.3—Stationarity analysis for streamwise mean velocity: MO-2, location 1, elevation =0.90 m above the bed

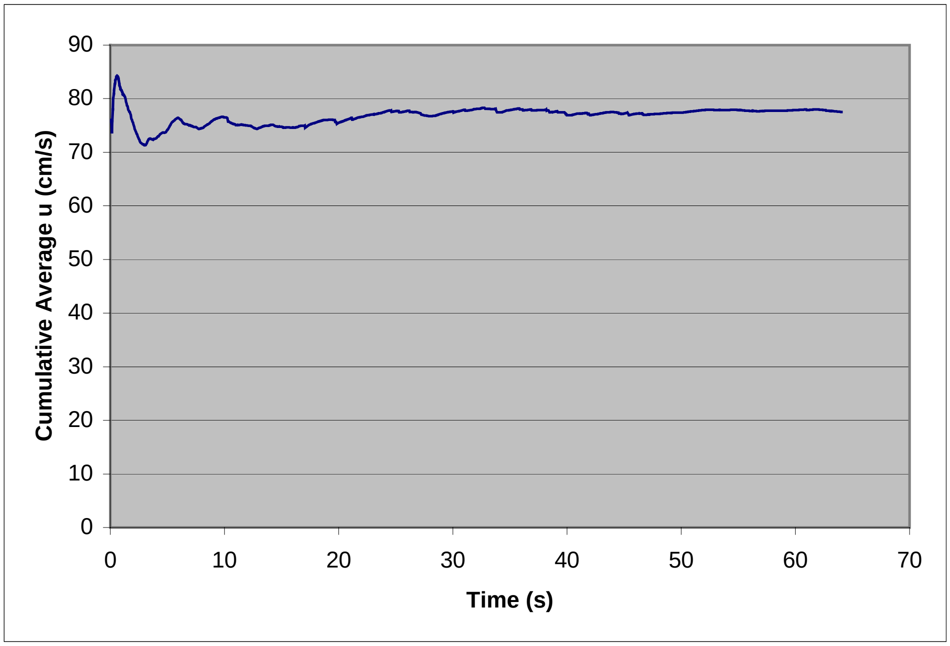


Figure 3.4—Stationarity analysis for streamwise mean velocity: MO-2, location 3, elevation =0.154 m above the bed

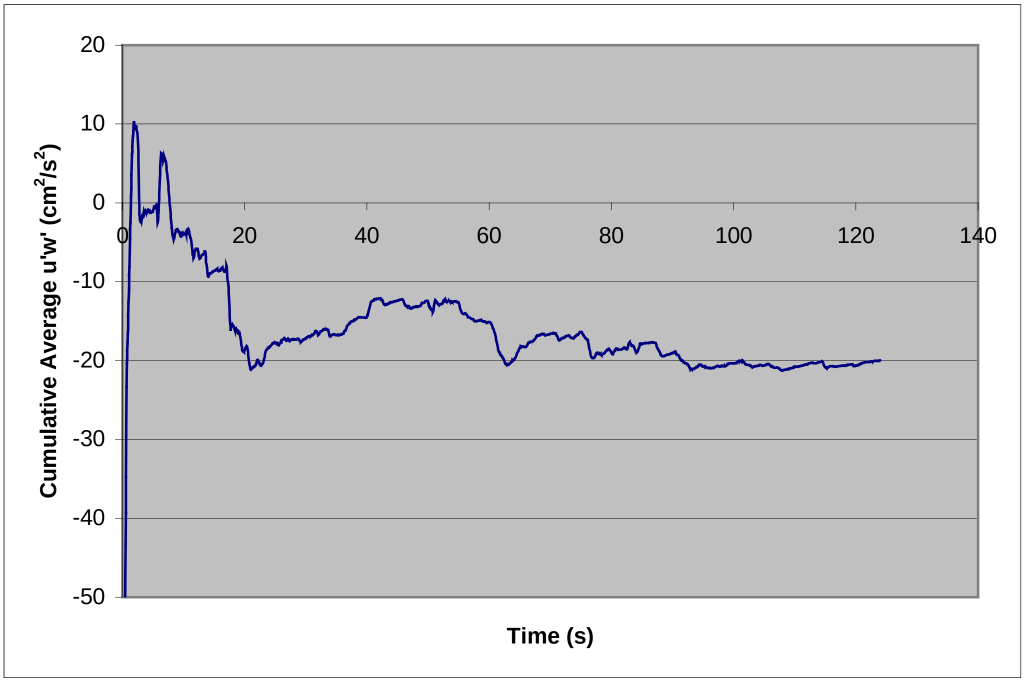


Figure 3.5—Stationarity analysis for average covariance of streamwise and vertical velocity fluctuations: MO-2, location 1, elevation =0.90 m above the bed

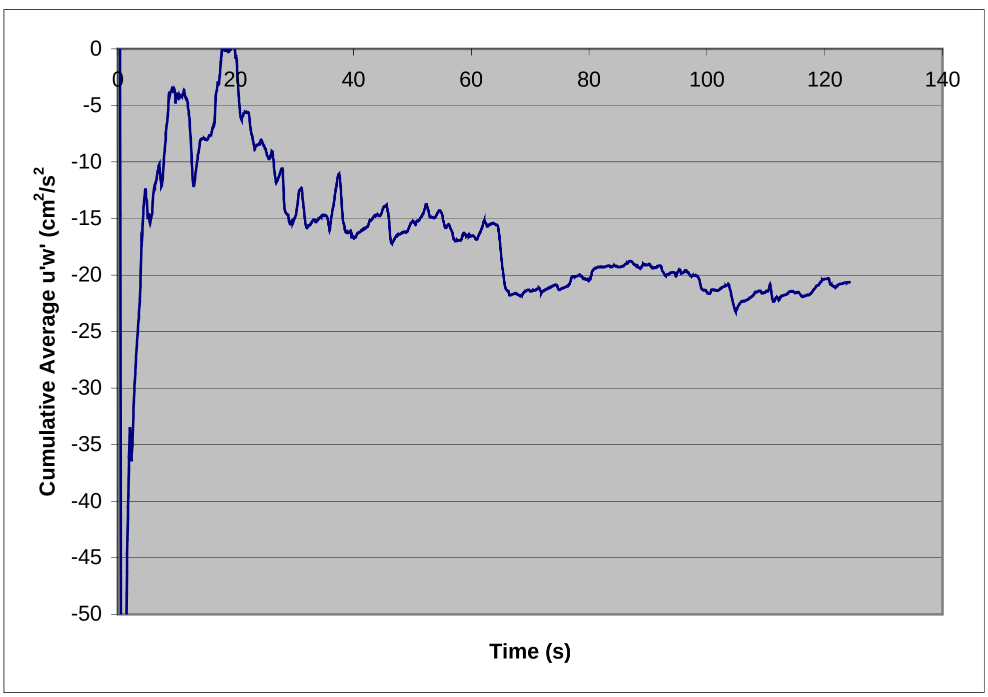


Figure 3.6—Stationarity analysis for average covariance of streamwise and vertical velocity fluctuations: MO-2, location 4, elevation =0.82 m above the bed

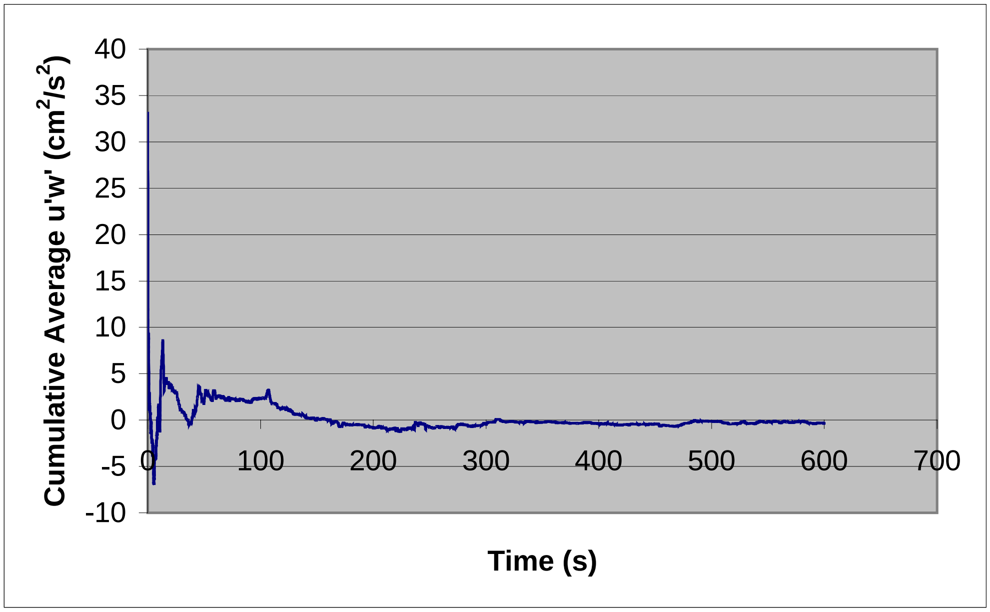


Figure 3.7—Stationarity analysis for average covariance of streamwise and vertical velocity fluctuations: MO-1, location 1, elevation =6.09 m above the bed

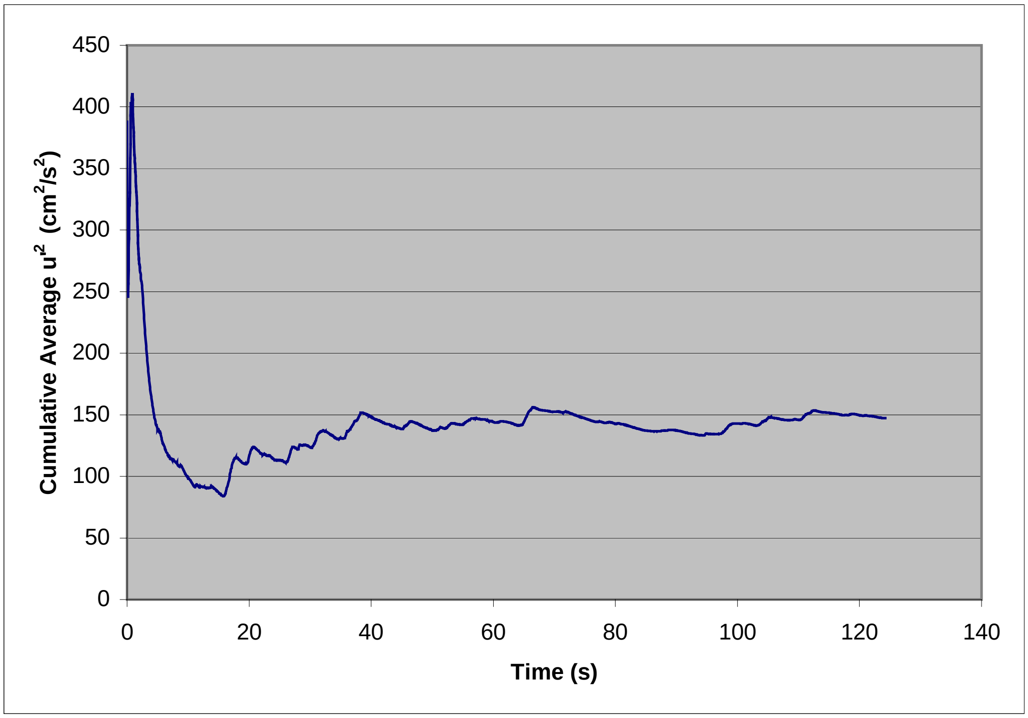


Figure 3.8—Stationarity analysis for streamwise turbulence intensity: MO-2, location 4, elevation =0.82 m above the bed

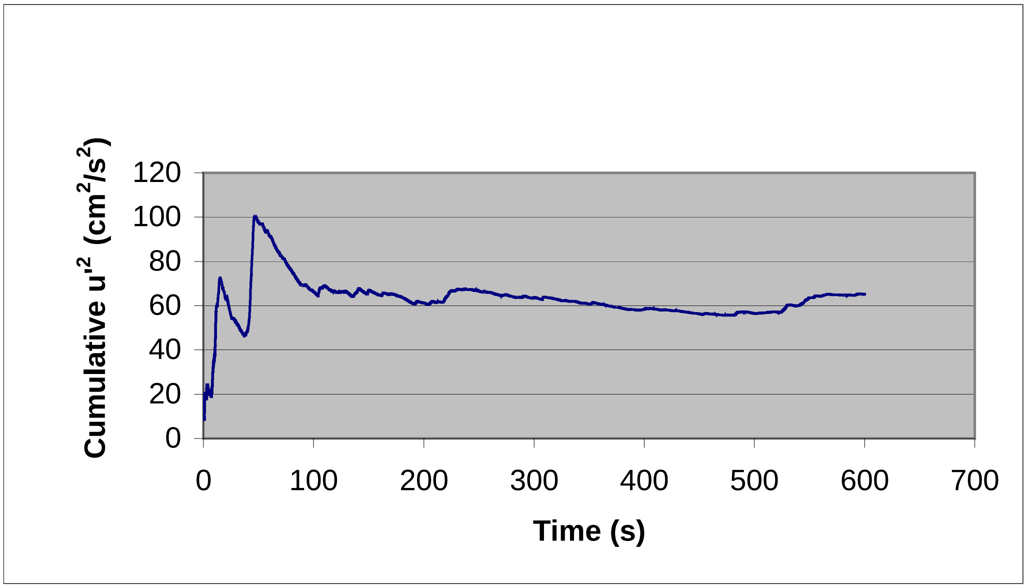


Figure 3.9—Stationarity analysis for streamwise turbulence intensity: MO-1, location 1, elevation =6.09 m above the bed

3.2.2 Acoustic Doppler Current Profiler

For the Missouri River data, the ADCP (figure 3.10) used in this research was a 600-kHz Rio Grande™ system manufactured by RD Instruments, with a maximum measurement frequency of 5-Hz with single ping (no averaging of signals) data. For the Kankakee River, a 1200-kHz system was used. Because of signal ringing, there is a blanking distance in the first 25 cm of flow, which when added to the draft of the ADCP in the water, eliminates approximately the top 0.75 m of the flow depth from velocity data collection. Side-lobe interference causes bias of the velocity measurements in a zone near the bed. The depth of this zone of interference is dependent on the depth of flow. A rule of thumb typically used is that this zone is approximately 6% of the flow depth (Kevin Oberg, U.S. Geological Survey, Office of Surface Water Acoustics Specialist, oral communication, 2002).

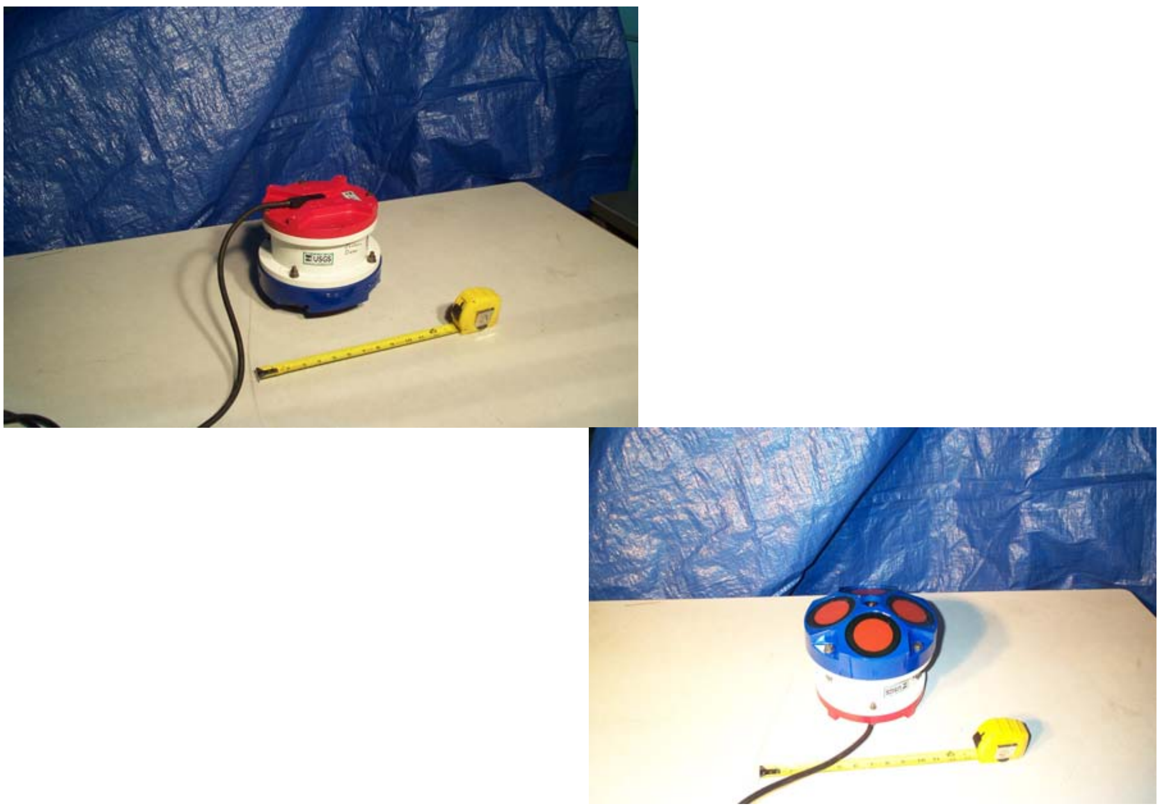
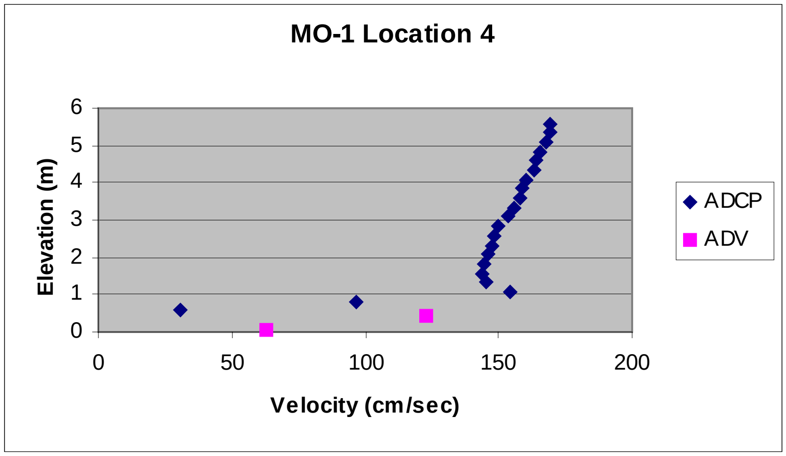


Figure 3.10—RD Instruments 600 kHz Rio Grande™ ADCP

The four divergent ADCP beams are utilized to determine the streamwise, lateral, and vertical velocities. Assuming spatial homogeneity of the flow in each of the four beams at equal distances from the instrument, the velocity vector can be computed using geometry. Care must be taken when using ADCP velocity data as any lack of spatial homogeneity can cause large errors in velocity determination in certain instances, such as areas where the flow is disturbed locally (such as near a bedform).

To examine how well the ADCP measures mean velocity in a dune environment; figure 3.11 contains profiles of the time-averaged streamwise velocities measured concurrently using the ADCP and an ADV for the Missouri and Kankakee Rivers. In figure 3.11A, it is evident that the ADCP data are in error below 1.5 m above the bed (assuming the ADV data to be correct). The bedforms in MO-1 had a small wavelength, and a larger steepness ratio than for the MO-2 data, which are shown in figure 3.11B. The MO-2 ADV and ADCP data appear to have much better agreement, although there is divergence starting within 1 meter of the bed. For figure 3.11C, in flow depths of about 2 m for the KANK-1 test, it is clear that the bottom 3 ADCP velocity data points are in error (assuming the ADV data to be correct). For most of the KANK-1 locations, the velocity data below 1 m above the bed were not used as these data were judged to be in error. Once the erroneous data near the bed are eliminated, the ADCP performs satisfactorily (figure 3.12), although a “smoothing” effect is noted. As a rule of thumb, the ADCP data below 1.5 meter from the bed were eliminated for the MO-1 tests and below 1.0 meter for the KANK-1 and MO-2 tests.   Plotting the velocity profiles in defect form assists in detecting any possible erroneous data near the bed (figure 3.13). Data points that are in gross misalignment with the rest of the data were deemed erroneous.

A



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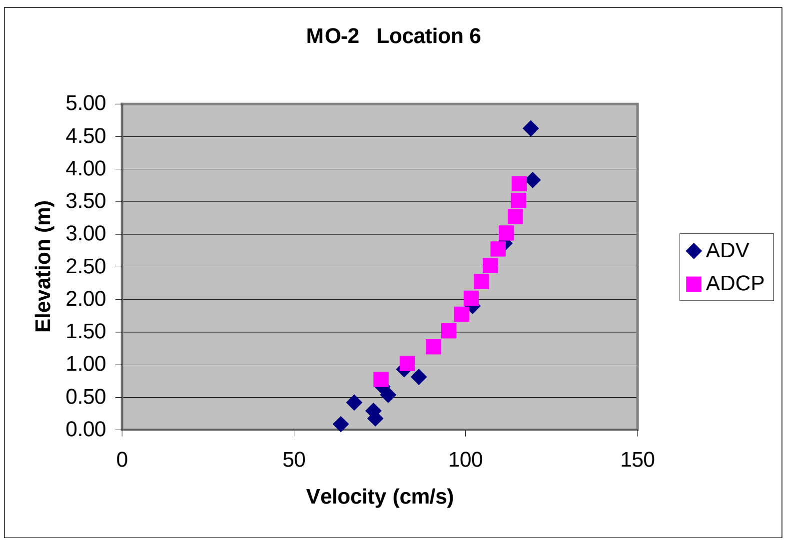

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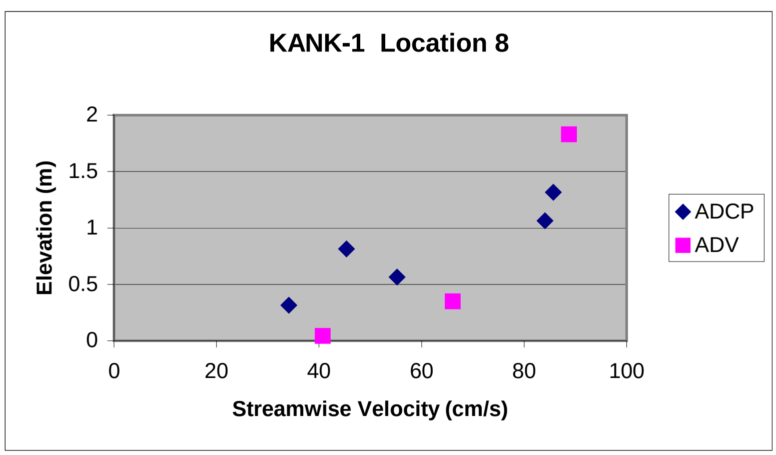


Figure 3.11---ADCP and ADV velocity profiles

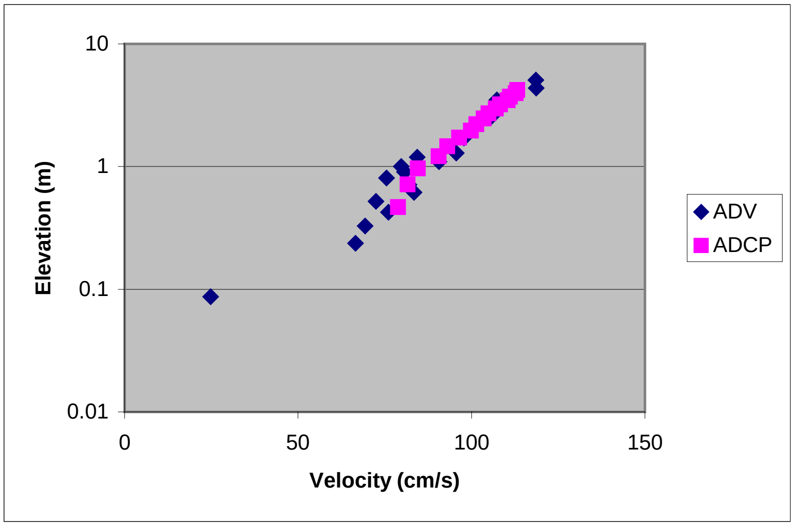


Figure 3.12—ADCP and ADV mean velocity data for MO-2, location 1

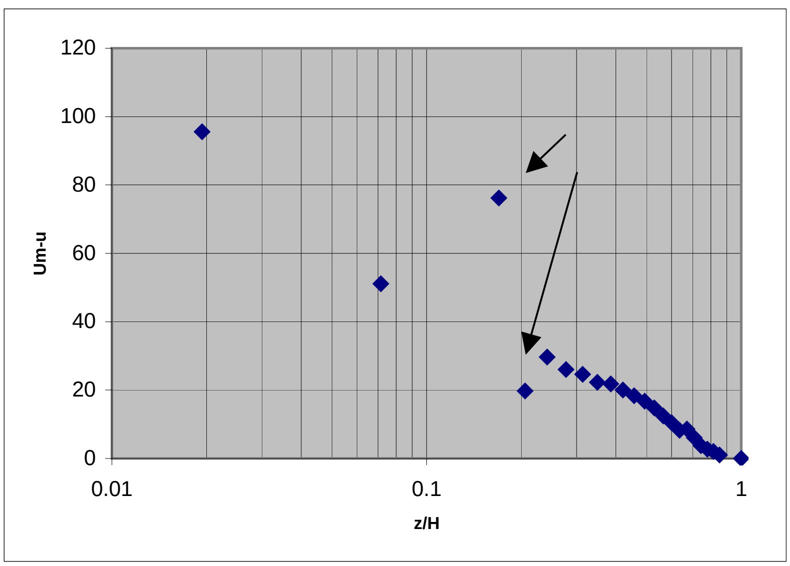


Figure 3.13—Mean velocity data in defect form

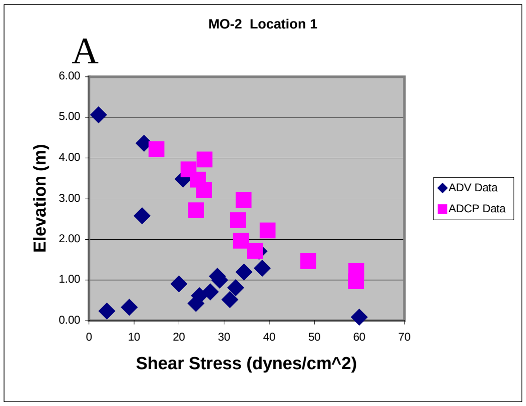
As previously discussed, turbulence properties can be extracted from ADCP data. Accuracy of these turbulence properties has been the subject of research conducted by the USGS at the University of Illinois Ven Te Chow Hydrosystems Laboratory (Nystrom, 1999; Nystrom and others, 2001; Nystrom and others, in press). Nystrom and others (in press) found that the Rio Grande ADCP had as low as 2% error for determination of mean velocity in low turbulence flow ($\sqrt{\overline{u'^2}}$ < 2cm/sec). In contrast to the ADV, where the three components of velocity are measured at a point and, thus, turbulence properties can be easily computed, the ADCP does not measure the three components of velocity at the same point. Therefore, individual beam velocity data must be used in a manner that allow the turbulence properties to be combined statistically. Stacey and others (1999) present the formulations whereby the variances of the beam velocities can be used to compute the streamwise-vertical and transverse-vertical Reynolds variances (and, thus, the Reynolds stresses) as

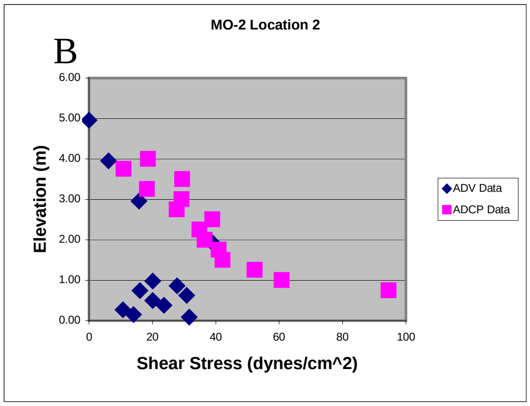
$$\overline{u'w'} = \frac{\overline{(u_3')^2} - \overline{(u_4')^2}}{4\sin(\theta)\cos(\theta)} \quad , \qquad [3.1]$$

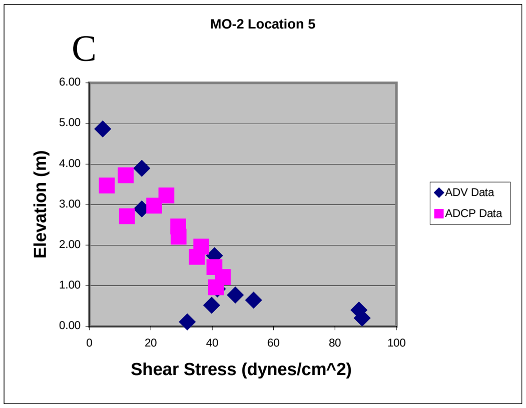
$$\overline{v'w'} = \frac{\overline{(u_1')^2} - \overline{(u_2')^2}}{4\sin(\theta)\cos(\theta)} \quad , \qquad [3.2]$$

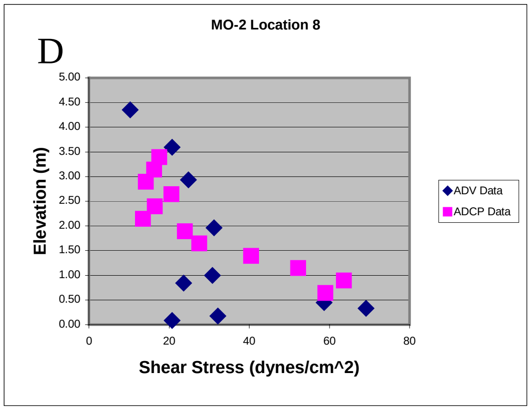
where u', v', w' are the fluctuations in the streamwise, transverse, and vertical velocities, θ is the beam-divergence angle of the ADCP (20 degrees in the case of the RD Instruments Rio Grande™ models used in this research), and u_1', u_2', u_3', and u_4' are the velocity fluctuations for beam 1, 2, 3, and 4, respectively (beam 3 orientation is upstream looking into the flow).

The ADCP does not store beam velocities automatically, without special commands. Unfortunately, beam velocities were not stored for the KANK-1 and MO-1 data sets; thus, no beam velocities are available for computation of Reynolds stresses for these data sets. Beam velocities were stored for MO-2 data. Reynolds stress results at five different locations along the MO-2 bedform field are shown in figure 3.14 shows. Although the individual, at-a-point estimates do not appear accurate (figure 3.15), the general trends of the ADCP Reynolds stress data appear to follow the patterns of the ADV Reynolds stresses above 1.5 m from the bed (figure 3.14). The average difference between the ADCP and ADV Reynolds stresses was 4.44 dynes/cm^2, with a standard deviation of 12.86 dynes/cm^2. These differences are similar to those found by Schemper and Admiraal (2002).









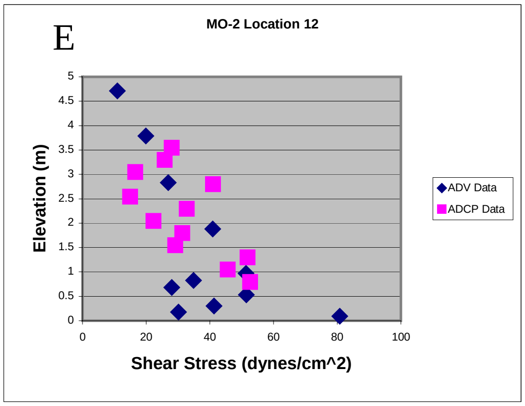


Figure 3.14—Reynolds shear stresses for selected MO-2 locations

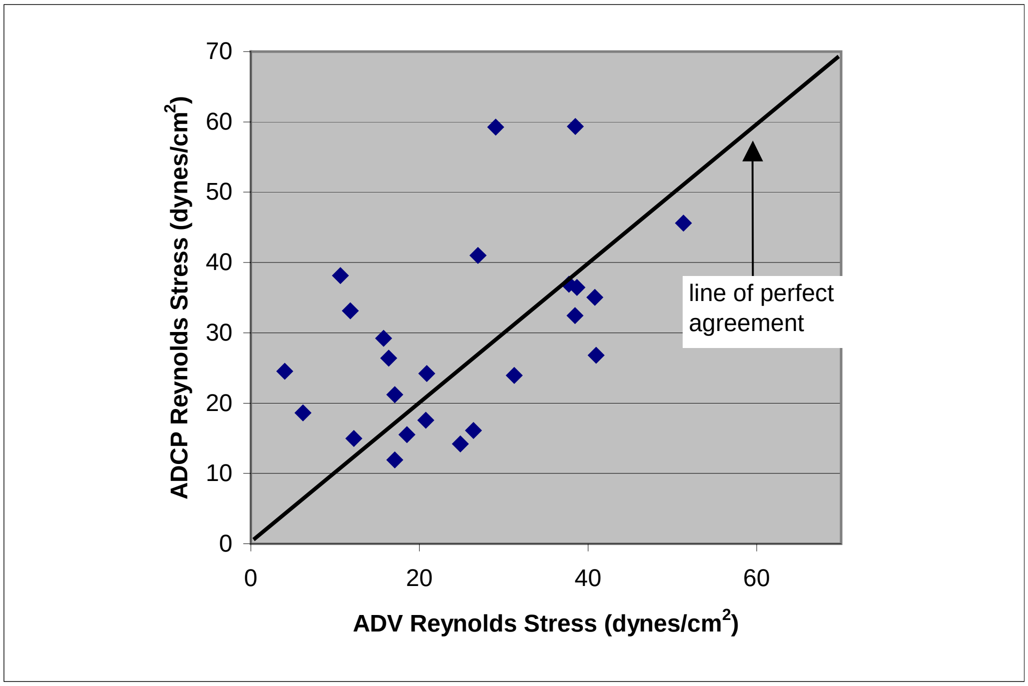


Figure 3.15—ADV and ADCP Reynolds stress comparison

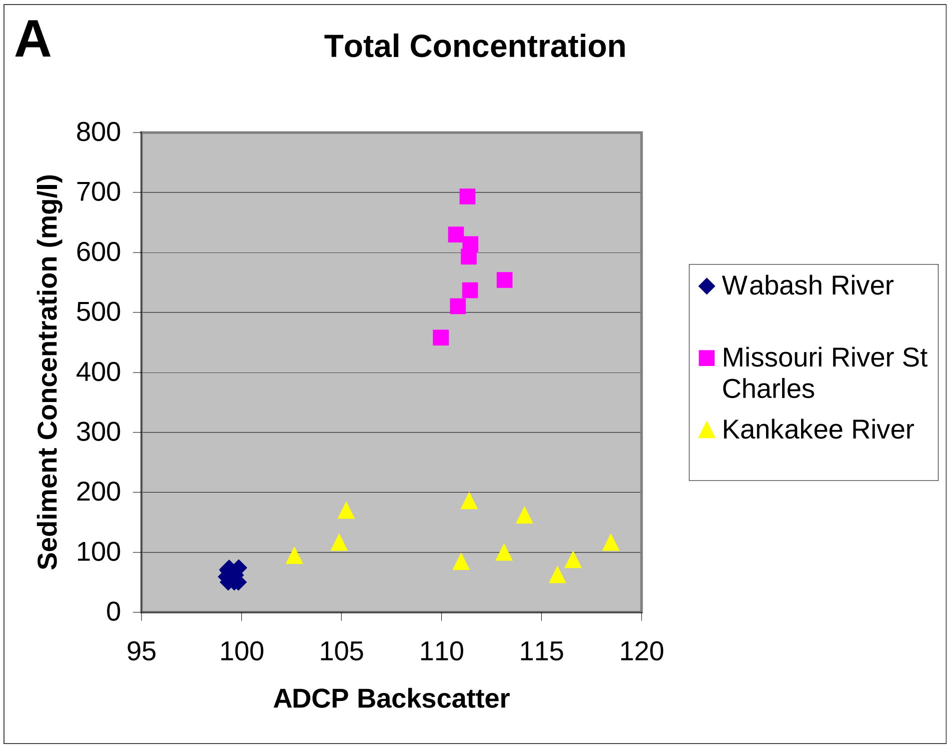
3.2.3. Sediment Data Collection

Suspended-sediment samples were collected through pump intakes mounted on the modified P-61 sampler frame (figures 3.1 and 3.2). These intakes were connected via tubing to a peristaltic pump that remained on board the boat. Laboratory analyses for sediment concentrations were conducted at the USGS sediment laboratory in Rolla, Missouri.

It was the original intent of this research to utilize ADCP backscatter intensities as surrogate measures of sediment concentration. Backscatter has been used in San Francisco Bay to estimate suspended-sediment concentration, with values found to be within 15% of Optical Backscatter (OBS) estimates of sediment concentration (Gartner and Cheng, 2001). However, upon analysis of sediment concentration and backscatter data collected for the MO-1 and KANK-1 tests along with a test of instrumentation conducted on the Wabash River near Cayuga, Indiana, no correlation between the two data sets was found for either total suspended-sediment concentration or suspended-sand concentration (figure 3.16).

OBS sensors also were tried in order to obtain continuous measures of suspended-sand concentration. The OBS sensor was tested on the Wabash River near Cayuga, Indiana. As was the case with ADCP backscatter intensity, no correlation was found between measured sand concentration and OBS voltage (figure 3.17).

Bed-material samples were collected for the Missouri River using a US BM-54 sediment sampler. The samples were analyzed for size distribution at the USGS sediment laboratory in Rolla, Missouri. The bed-material size distribution for the Kankakee River was taken from the extensive bed-material data found in Bhowmik and others (1980). The size analysis data for the Missouri and Kankakee Rivers is shown in figure 3.18.



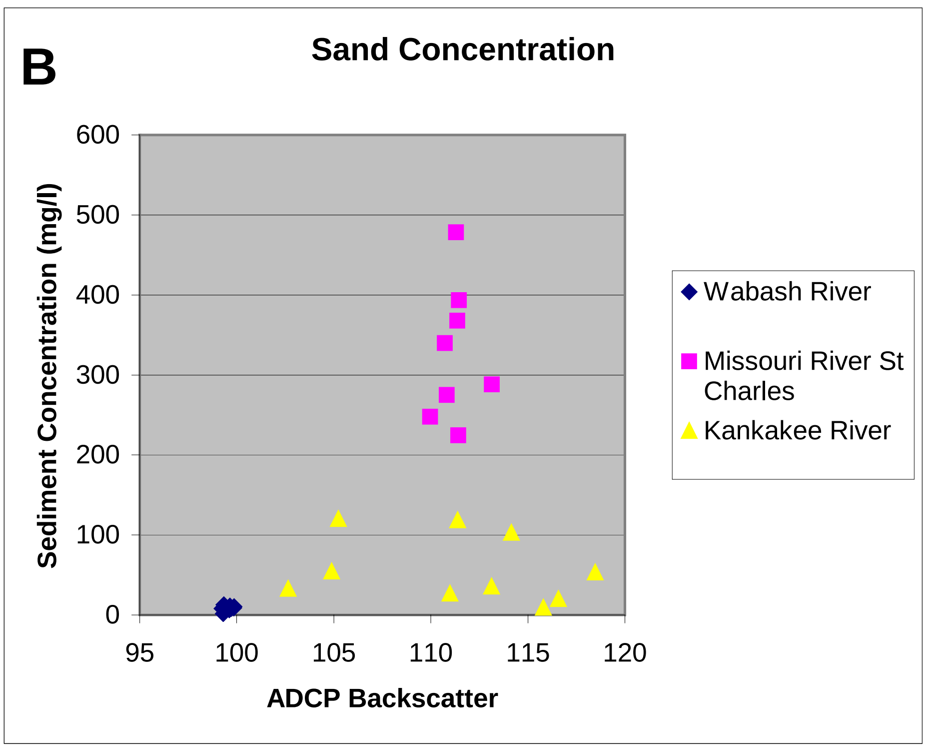


Figure 3.16—ADCP backscatter intensities compared with measured sediment concentrations A) total suspended-sediment concentration, B) suspended-sand concentration

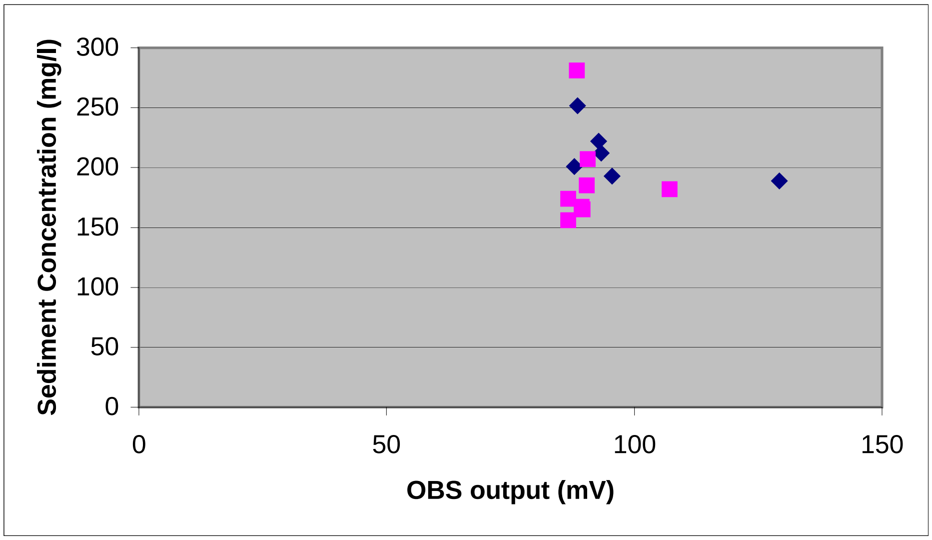


Figure 3.17—Optical backscatter readings and measured suspended-sediment concentrations, Wabash River near Cayuga, Indiana

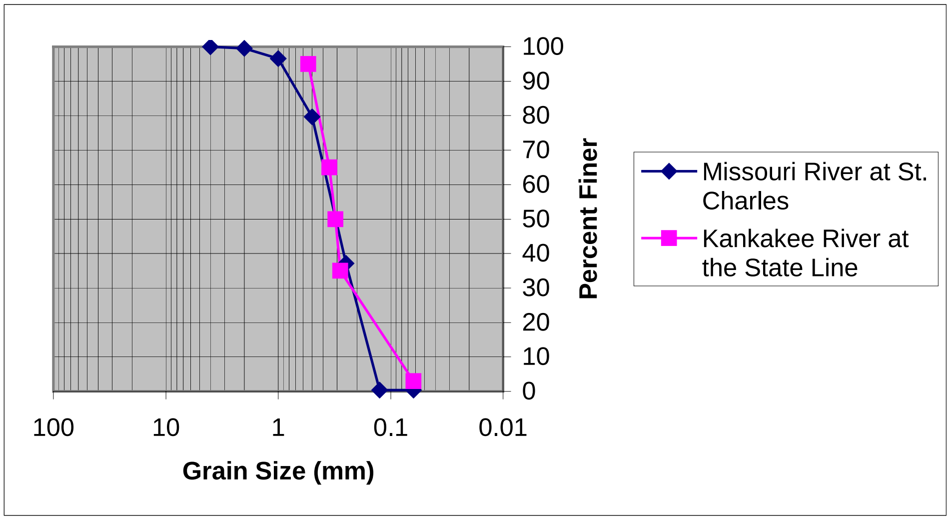


Figure 3.18—Bed-material size distributions for the Missouri River at St. Charles and the Kankakee River at the State Line

3.3. Design and Testing of Instrument Platform

The original idea for the near-bed data collection effort was to specially fabricate a platform (figure 3.19) to enable the data-collection instrumentation to be lowered to the bed using a crane mounted on the bow of the USGS research boat M/V Mackinaw. Similar types of mounts have been deployed in estuaries, for example that of Cheng and others (2000) as shown in figure 3.20. After much consideration, a beta design was finalized and a prototype built and flume tested during this research (figure 3.21). This testing was completed to verify that the platform superstructure caused no alteration of the flow field (acceleration, extra turbulence, etc) at the velocity measurement locations. Because of the large drag anticipated on the platform, it was designed with extra counterweights in the legs to increase stability in the water. Unfortunately, the platform proved too heavy (136 kg) for the available research boat to maneuver, and, thus, this platform had to be abandoned for a lighter, more streamlined platform.

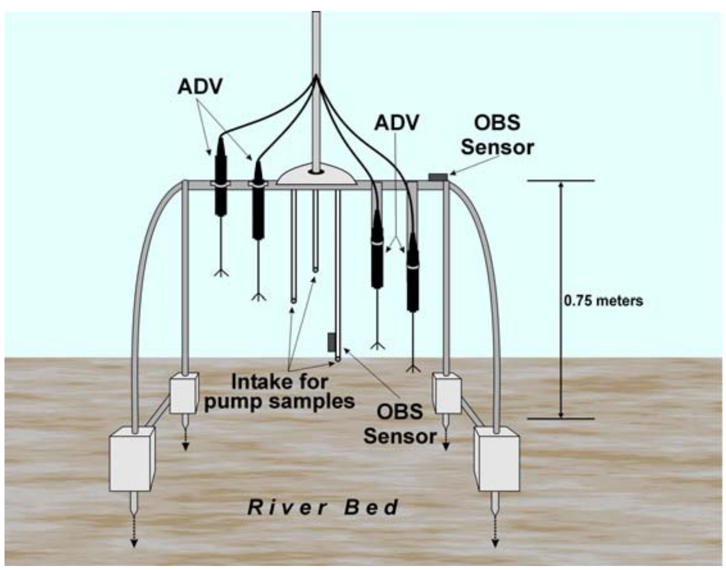


Figure 3.19.---Conceptual sketch of the near-bed data-collection platform (looking upstream)

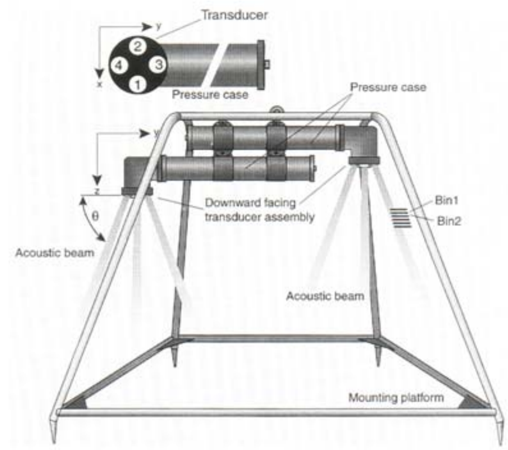


Figure 3.20.—Instrument platform used for data collection in San Francisco Bay (Cheng and others, 2000)

Figure 3.21—Prototype of beta version of the data-collection platform for this research

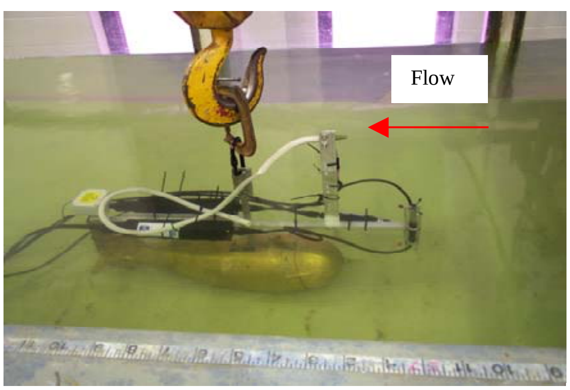
A P-61 sediment sampler was used as the base of the new platform, and a stiffened aluminum brace was built to mount the ADVs, the compass/tilt/roll sensor, and the sediment intakes on the P-61 sampler (figure 3.1 and 3.2). A concern was that the body of the P-61 or the brace would create flow disturbances such that velocity data would be biased. This concerned was mitigated in that the P-61 went through extensive testing to assure isokinetic sampling capabilities during its original design.

Testing of the modified P-61 sampler was carried out in the large tilting flume (figure 3.22) at the Ven Te Chow Hydrosystems laboratory at the University of Illinois at Urbana-Champaign. This flume is approximately 48-m long and 1.8-m wide. The flume had a sand bed (installed for other experiments) and Plexiglas ™ side walls. Flow is supplied to the flume by pumps that re-circulate the water through a system of channels and sumps.

Figure 3.22—Overhead view of large tilting flume at the Ven Te Chow Hydrosystems Laboratory

The modified P-61 platform (figure 3.23) was lowered into the middle of the flume with the laboratory overhead crane. Approximately 3 m upstream, another ADV was mounted to a vertical pointer (figure 3.24), that could be adjusted to measure the undisturbed ambient water velocities at the same elevations above the bed as the ADVs mounted on the modified P-61.

The uppermost ADV on the P-61 was positioned 52.16 cm above the laboratory flume bed. With the depth of flow required to submerge the sampling volume of this upward-looking ADV, the maximum flow velocity possible in the flume was approximately 16 cm/s. Comparison of results for the upstream ADV (measuring the ambient water velocity) and the uppermost ADV on the modified P-61 indicates essentially no difference in measured water velocity (-0.72% difference) for this flow.



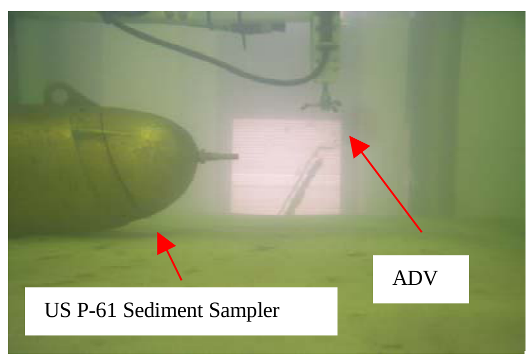


Figure 3.23—Modified P-61 platform with ADVs positioned in center of large tilting flume

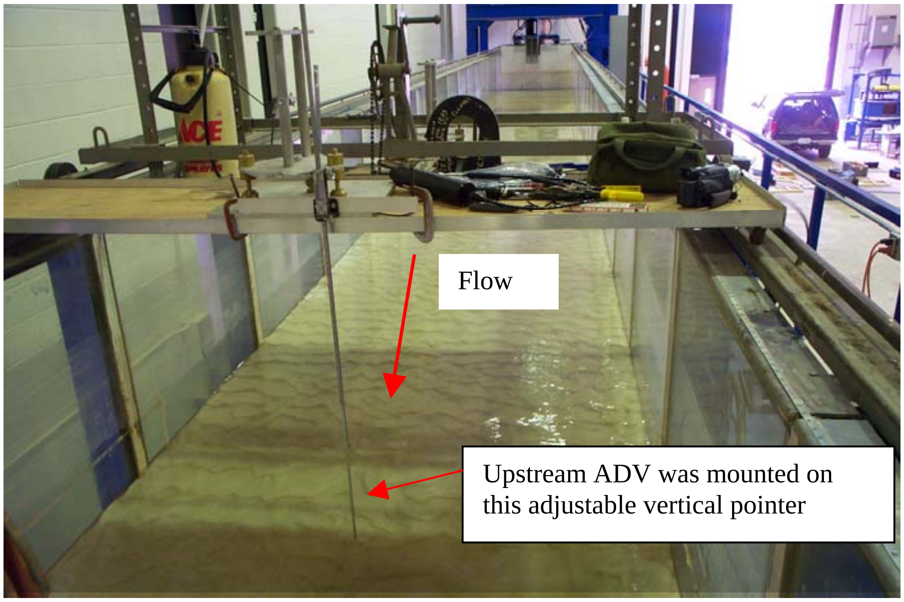


Figure 3.24—Mounting for upstream ADV

The sampling volume for the bottommost downward-looking ADV on the P-61 was 11.7 cm above the laboratory flume bed, which allowed a lower depth of flow for submergence than the uppermost ADV, resulting in a wider range of the tested velocities. A positive biasing of the velocity (from 5% to 7%) occurs at the higher velocities (figure 3.25). This bias results most likely because of flow acceleration approaching the P-61 head. To eliminate this bias, the aluminum brace could be extended forward. This extension was deemed unacceptable as it was thought to 1) increase the slenderness ratio of the front brace, which would allow increased vibration that negatively would affect the turbulence measurements; 2) increase the risk of damaging the ADV probe because the probe would be far away from the main body of the P-61; and 3) being limited by a lack of flexible cable slack. Therefore, the ADV field data have a positive bias for the bottommost ADV of around 5%; however, because of the nature of field data and the good agreement between ADV and ADCP data (figure 3.11), no effort was made to correct for this bias.

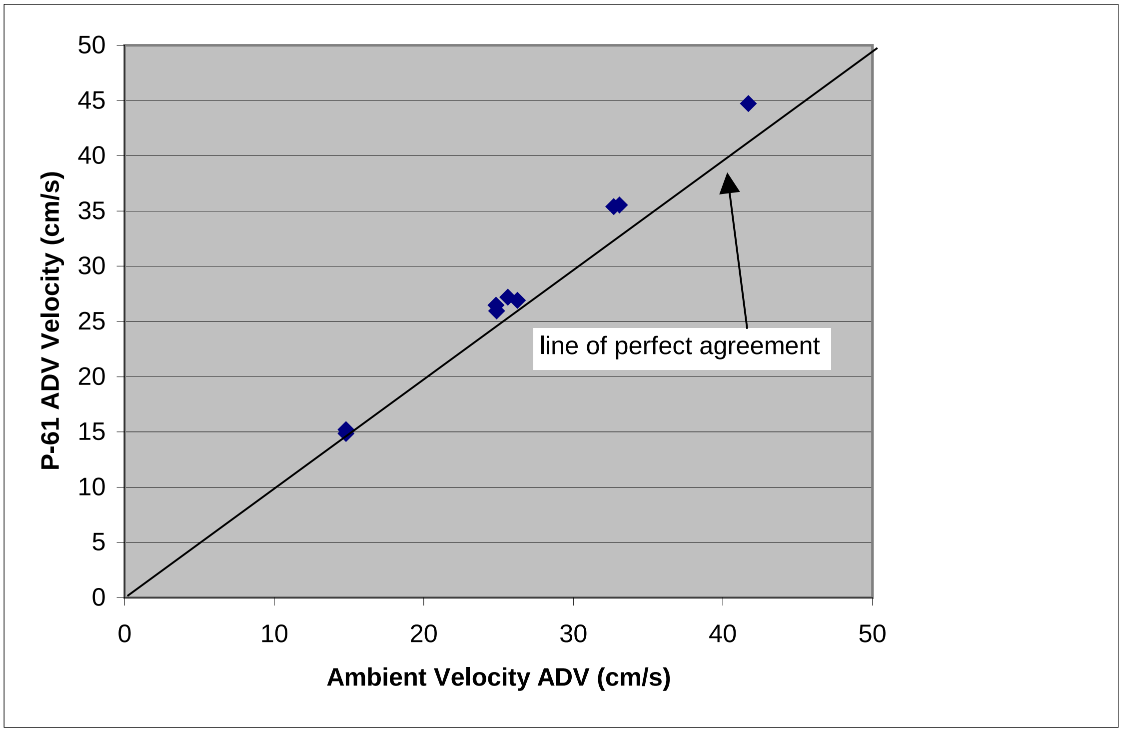


Figure 3.25—Ambient ADV velocity and P-61 platform ADV velocity

3.4 Description of Field Sites

3.4.1. Kankakee River

The Kankakee River at the Illinois-Indiana State Line study site (figure 3.26) originally was chosen because of its straight approach reach and because of the relatively shallow depth at high flow (as compared to other rivers). This site allowed for a good test of equipment and procedures before attempting data collection in a much larger river system (such as the Missouri or Mississippi Rivers).

The reach of the Kankakee River (above and including the study reach) was straightened and channelized as early as the 1860's to lessen flooding and to assist in draining swampland areas. By 1918, the Indiana portion of the Kankakee River had been straightened and completely channelized, decreasing the channel length in the Indiana reach of the river from 400 km to 131 km (Holmes, 1997), which resulted in increased sediment transport capacity. Bedforms are prevalent in this reach of the river.

In the study reach, the river is straight and flows in a due west direction. The study reach is approximately 14.9 km upstream from the Momence, Illinois dam (also USGS streamflow-gaging station 05520500), and 17.3 km downstream from the USGS streamflow-gaging station at Shelby, Indiana (05578000). The channel bed is composed of fairly uniform sand with a D_{50} of approximately 0.31 mm (figure 3.18). The channel-top width is approximately 50 m for bankfull discharge, with trees lining both sides of the river (figure 3.27). At bankfull flow, flow depths are no more than 2 to 2.5 m in the deepest parts of the channel. The downstream end of the reach (near the State-Line bridge) has a large sand deposit that is present during both high and low flows.

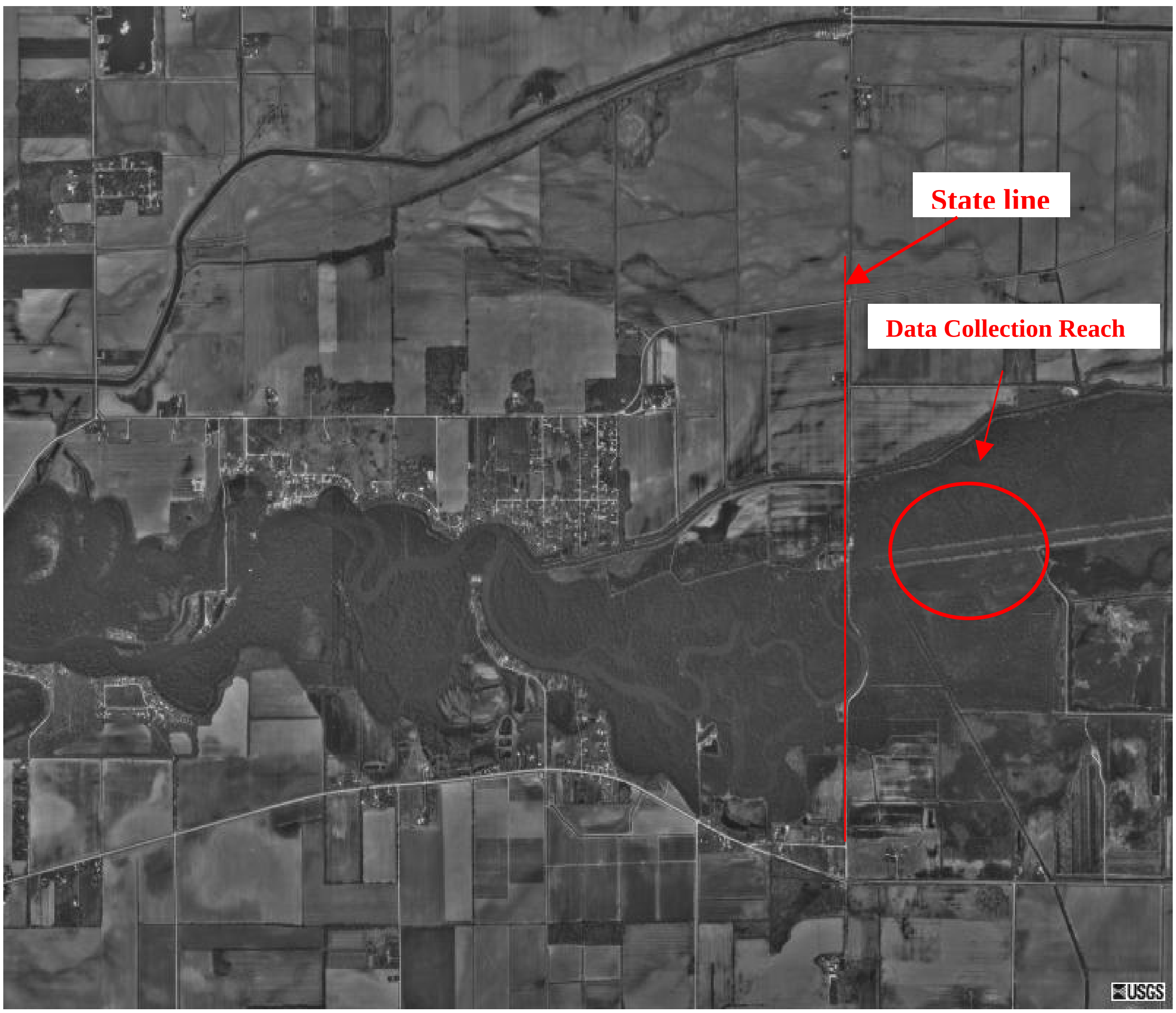


Figure 3.26—Plan view of the Kankakee River at the Illinois-Indiana State Line

Figure 3.27—Kankakee River looking upstream along the study reach

3.4.2. Missouri River

For the large river site, the original research plan was to collect data on the Mississippi River at St. Louis, Missouri. This site was selected, preliminarily, based on the history of sediment-data collection in this area by both the USGS (Jordan, 1965; Scott and Stephens, 1966) and the U.S. Army Corps of Engineers (Corps). However, three main issues prevented data collection at St. Louis: 1) logistically, it was too time consuming to transfer all the necessary research boats and associated data-collection equipment to the data-collection site (the nearest boat launch was 10 river miles away); 2) during the time span allotted for the data collection, the Mississippi River was at a moderate flow rate and associated water level, with bedform height to depth ratio of 1/11 (this ratio was far enough below the literature value of 1/6 for equilibrium conditions for dunes(Garcia, 1999) that this precluded the assumption of equilibrium conditions); and 3) there was appreciable barge traffic in the area where bedforms were present, thus, preventing safe anchoring of the data-collection boat.

The Missouri River at St. Charles, Missouri was chosen as an alternative site because it provided 1) good logistics (with the boat launch adjacent to the data-collection reach); 2) approximate equilibrium dimensions for dunes (dune height to water depth ratios around 1/6 to 1/7); and 3) minimal barge traffic.

The Missouri River is part of a highly altered river system compared to its historic conditions as found by the American explorers Lewis and Clark in 1804. The Missouri River has been transformed from a highly braided channel to a fairly uniform channel, largely the result of the many river-training structures built by the Corps to allow river navigation. In addition, the sediment load has been drastically reduced as the result of the main-stem Missouri River reservoir dams that came on line in the mid-20th century. However, the river still is sinuous in many reaches.

In the study reach (figure 3.28), the river is fairly straight and flows to the northeast. The study reach is approximately 44.6 km upstream from the confluence with the Mississippi

River. A USGS streamflow-gaging station (06935965) is immediately adjacent to the study reach, with a Corps of Engineers maintained gaging station 44.6 km downstream at Alton, Illinois, and a wire-weight gage maintained by the National Weather Service 53 km upstream at Washington, Missouri.

The channel bed is composed of fairly uniform sand with a D_{50} of approximately 0.31 mm (figure 3.18). The channel-top width is approximately between 350 and 400 meters for the study reach at the discharges present in this study. The flows for data collection during this research were well within the channel banks, which are lined with trees and riprap on both sides (figure 3.29).

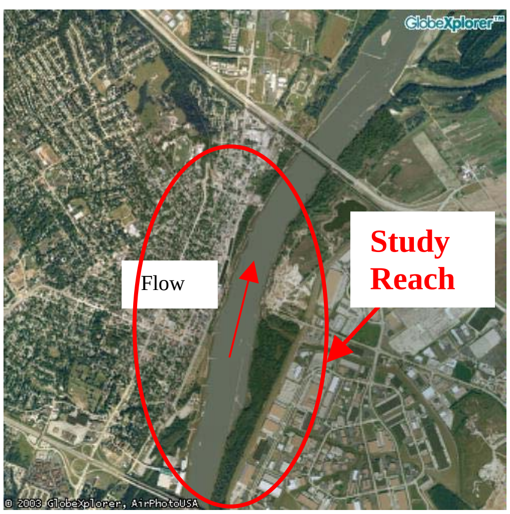


Figure 3.28—Plan view of the Missouri River at St Charles, Missouri

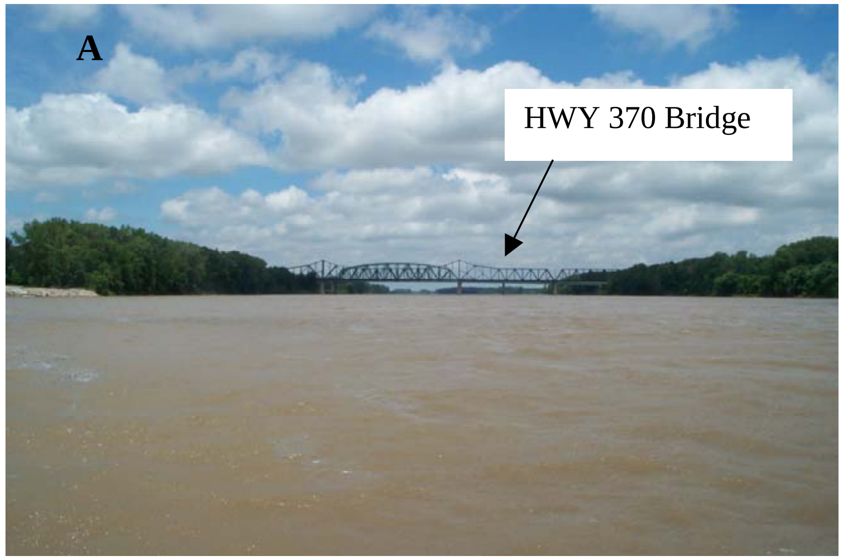


Figure 3.29—Missouri River (A) looking downstream through the study reach; (B) looking from right bank to left bank